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## On the Relativistic Theory of Image Formation in an Electron Microscope

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illusions and by the fact that we can resolve retinal images that are smaller than the wavelength of light--an apparent physical impossibility!

The hierarchical architecture of the functional anatomy of the retina and other areas of the visual system will be discussed. Our relatively poor texture discrimination ability will be demonstrated, the development of natural camouflage being an obvious example.

There is no theoretical physical limit to the level of complexity of the machines we can build, and soon there will be texture and image analysers that will be more powerful (in this respect!) than our own brains. We will not be able to conceptualise the answers that they give us, but this will not matter because these numerical results will be entirely objective and will free us from the subjective and highly synthetic action of our own sensory systems.

#### ON THE RELATIVISTIC THEORY OF IMAGE FORMATION IN AN ELECTRON MICROSCOPE

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The basis for the presently used theory of image formation in an electron microscope (EM), culminating in transfer theory, is the non-relativistic Schrödinger wave equation. This theory, as developed by glaser as early as 1952, is also widely used in case the acceleration voltage is larger than, say, 75 kV, in which case relativistic "corrections" become important. The difference between the relativistic and classical velocity is then already 10% of the classical velocity, and becomes even 25% for 200 kV electrons. It is common belief that the relativistic theory of image formation can be deduced from the nonrelativistic theory replacing the rest mass  $m_0$  of the electron by its relativistic value

$$m_0 (1 - \frac{v^2}{c^2})^{-1/2},$$

viz. The calculation of the aberration coefficients starts from the nonrelativistic integrals derived by Glaser, which are modified by the replacement

$$m_0 \rightarrow m_0 (1 - \frac{v^2}{c^2})^{-1/2}.$$

The validity of this replacement is unfortunately not easily made plausible by heuristic argument, starting from the appropriate relativistic wave equation of Dirac, which leads the authors to a full investigation of the relativistic theory of image formation. We will present the results of our calculations in a non-technical way and show the surprising validity of the replacement

$$m_0 \rightarrow m_0 (1 - \frac{v^2}{c^2})^{-1/2}.$$

#### STRUCTURE ANALYSIS OF BIOLOGICAL MACROMOLECULES USING PATTERN RECOGNITION

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Noise is the major problem in the interpretation of electron microscopical images of biological macromolecules. The radiation-sensitive molecules rapidly disintegrate during the electron radiation exposure needed to register an image with a sufficiently high signal-to-noise ratio for direct visual interpretation. The alternative is to register a very large number of individual molecular images using a low electron exposure and to average the very noisy individual images to increase the signal-to-noise ratio.

Averaging techniques for molecules arranged in regular arrays, originally proposed by Klug and co-workers<sup>1</sup>, led to impressive results in the case of the purple membrane.<sup>2</sup> Techniques to align and average single molecular images were developed later, mainly by Frank and co-workers.<sup>3</sup> In contrast to molecules arranged in crystals, single molecules are not kept in a fixed position by their neighbors and hence they exhibit a great orientational freedom in the electron microscopical preparation. This orientation freedom has to be taken into account prior to the averaging.

Eigenvector eigenvalue analysis methods were introduced to this field of research<sup>4</sup> in the form of correspond-